

**We claim:**

1           1.    An   optical   router   for   routing   wavelength  
2   channels   received   in   bundles   of   wavelength   channels,   the  
3   router   comprising:

4           a   plurality   of   wavelength   filters,   one   filter   of   the  
5   plurality   of   wavelength   filters   per   bundle,   each   filter   of  
6   the   plurality   of   wavelength   filters   being   capable   of  
7   separating   one   or   more   wavelength   channels   from   the   bundle  
8   associated   with   the   filter;

9           a   plurality   of   wavelength   converters,   one   converter  
10   of   the   plurality   of   wavelength   converters   per   bundle,   each  
11   converter   being   capable   of   receiving   an   add   wavelength  
12   channel   and   converting   the   received   add   wavelength   channel  
13   to   a   transformed   wavelength;

14          a   plurality   of   multiplexing   units,   one   multiplexing  
15   unit   of   the   plurality   of   multiplexing   units   per   bundle,  
16   each   multiplexing   unit   of   the   plurality   of   multiplexing  
17   units   being   capable   of   multiplexing   at   least   a   subset   of  
18   channels   of   the   bundle   associated   with   said   each  
19   multiplexing   unit   and   the   add   wavelength   channel   converted  
20   by   the   converter   associated   with   the   bundle   that   is  
21   associated   with   said   each   multiplexing   unit;

22 a first spatial switching fabric comprising a  
23 plurality of inputs and a plurality of outputs, the inputs  
24 of the first spatial switching fabric being coupled to the  
25 plurality of wavelength filters to receive the separated  
26 one or more wavelength channels; and

27 a plurality of channel combiners, one channel  
28 combiner of the plurality of channel combiners per  
29 multiplexing unit of the plurality of multiplexing units,  
30 each channel combiner of the plurality of channel  
31 combiners being coupled to a different one of the outputs  
32 of the plurality of outputs of the first spatial switching  
33 fabric, said each channel combiner being capable of  
34 receiving and multiplexing channels received from the  
35 corresponding output of the plurality of outputs of the  
36 first spatial switching fabric and the channels  
37 multiplexed by the multiplexing unit associated with said  
38 each channel combiner.

1 2. An optical router according to claim 1, wherein  
2 said each filter of the plurality of wavelength filters  
3 comprises a tunable band pass filter capable of separating  
4 different one or more wavelength channels.

1        3. An optical router according to claim 2, wherein  
2 said each converter of the plurality of wavelength  
3 converters comprises a tunable pump source capable of  
4 producing pump output at different wavelengths to enable  
5 said each converter to convert the received add wavelength  
6 channel to different transformed wavelengths.

1        4. An optical router according to claim 1, wherein  
2 said each wavelength filter of the plurality of wavelength  
3 filters comprises a circulator having consecutive first,  
4 second, and third ports, and a Bragg grating coupled to  
5 the third port of the circulator.

1        5. An optical router according to claim 4, wherein  
2 the Bragg grating of said each wavelength filter is a  
3 tunable Bragg grating capable of being adjusted to reflect  
4 different wavelengths.

1        6. An optical router according to claim 1, wherein  
2 said each wavelength filter of the plurality of wavelength  
3 filters comprises:

4        a fused fiber optical power splitter comprising an  
5 input path capable of receiving the bundle associated with  
6 said each wavelength filter, a pass-through output path

7 for outputting at least the subset of channels of the  
8 bundle associated with said each wavelength filter, and a  
9 first separated output path capable of outputting the one  
10 or more wavelength channels separated from the bundle  
11 associated with said each wavelength filter; and

12 a first band pass filtering element coupled to the  
13 first separated output path so that the one or more  
14 wavelength channels separated from the bundle associated  
15 with said each wavelength filter pass through the first  
16 band pass filtering element, the first band pass filtering  
17 element having a first passband.

1 7. An optical router according to claim 6, wherein:  
2 the fused fiber optical power splitter of said each  
3 wavelength filter further comprises a second separated  
4 output path capable of outputting the one or more  
5 wavelength channels separated from the bundle associated  
6 with said each wavelength filter; and

7 said each wavelength filter further comprises a  
8 second band pass filtering element coupled to the second  
9 separated output path so that the one or more wavelength  
10 channels separated from the bundle associated with said  
11 each wavelength filter pass through the second band pass

12 filtering element, the second band pass filtering element  
13 having a second passband.

1 8. An optical router according to claim 6, wherein  
2 said each wavelength filter further comprises active fiber  
3 filler in the first separated output path, the active  
4 fiber filler being for amplifying the one or more  
5 wavelength channels separated from the bundle associated  
6 with said each wavelength filter.

1 9. An optical router according to claim 6, wherein  
2 said each wavelength filter further comprises a pass-  
3 through band reject filtering element coupled to the pass-  
4 through output path for removing the one or more  
5 wavelength channels separated from the bundle associated  
6 with said each wavelength filter from the subset of  
7 channels of the bundle associated with said each  
8 wavelength filter.

1 10. An optical router according to claim 9, wherein:  
2 the pass-through band reject filtering element of  
3 said each wavelength filter comprises a tunable pass  
4 through filtering element capable of being adjusted to  
5 reject different wavelengths; and

6 the first band pass filtering element comprises a  
7 first tunable filtering element capable of being adjusted  
8 to transmit different wavelengths.

1 11. An optical router according to claim 1, wherein  
2 said each converter of the plurality of wavelength  
3 converters comprises a difference frequency mixer.

1 12. An optical router according to claim 11,  
2 wherein:

3 said each filter of the plurality of wavelength  
4 filters comprises a tunable band pass filter capable of  
5 separating different one or more wavelength channels; and

6 the difference frequency mixer of said each converter  
7 of the plurality of wavelength converters comprises a  
8 tunable pump source capable of producing pump output at  
9 different wavelengths to enable said each converter to  
10 convert the received add wavelength channel to different  
11 transformed wavelengths.

1 13. An optical router according to claim 1, wherein  
2 said each converter of the plurality of wavelength  
3 converters comprises a cross-gain modulator.

1        14. An optical router according to claim 13,  
2 wherein:

3        said each filter of the plurality of wavelength  
4 filters comprises a tunable band pass filter capable of  
5 separating different one or more wavelength channels; and  
6        the cross-gain modulator of said each converter of  
7 the plurality of wavelength converters comprises a tunable  
8 pump source capable of producing pump output at different  
9 wavelengths to enable said each converter to convert the  
10 received add wavelength channel to different transformed  
11 wavelengths.

1        15. An optical router according to claim 1, wherein  
2 said each converter of the plurality of wavelength  
3 converters comprises a cross-phase modulator.

1        16. An optical router according to claim 13,  
2 wherein:

3        said each filter of the plurality of wavelength  
4 filters comprises a tunable band pass filter capable of  
5 separating different one or more wavelength channels; and  
6        the cross-phase modulator of said each converter of  
7 the plurality of wavelength converters comprises a tunable

8 pump source capable of producing pump output at different  
9 wavelengths to enable said each converter to convert the  
10 received add wavelength channel to different transformed  
11 wavelengths.

1 17. An optical router according to claim 1, wherein  
2 said each converter of the plurality of wavelength  
3 converters comprises a four-wave mixer.

1 18. An optical router according to claim 13,  
2 wherein:

3 said each filter of the plurality of wavelength  
4 filters comprises a tunable band pass filter capable of  
5 separating different one or more wavelength channels; and

6 the four-wave mixer of said each converter of the  
7 plurality of wavelength converters comprises a tunable  
8 pump source capable of producing pump output at different  
9 wavelengths to enable said each converter to convert the  
10 received add wavelength channel to different transformed  
11 wavelengths.

1 19. An optical router according to claim 1, further  
2 comprising a plurality of power equalizers, one equalizer  
3 per wavelength converter of the plurality of wavelength



4 converters, each equalizer being interposed between the  
5 converter associated with said each equalizer and the  
6 multiplexing unit corresponding to the wavelength  
7 converter associated with said each equalizer.

1 20. An optical router according to claim 1, wherein  
2 said each multiplexing unit comprises a circulator.

1 21. An optical router according to claim 3, wherein  
2 said each multiplexing unit comprises a circulator.

1 22. An optical router according to claim 1, wherein  
2 said each multiplexing unit comprises a fused fiber  
3 optical power splitter.

1 23. An optical router according to claim 3, wherein  
2 said each multiplexing unit comprises a fused fiber  
3 optical power splitter.

1 24. An optical router according to claim 1, further  
2 comprising a second spatial switching fabric comprising a  
3 plurality of inputs and a plurality of outputs, one input  
4 of the plurality of inputs of the second spatial switching  
5 fabric per channel combiner of the plurality of channel

6 combiners, each input of the plurality of inputs of the  
7 second spatial switching fabric being coupled to the  
8 channel combiner associated with said each input of the  
9 plurality of inputs of the second spatial switching fabric  
10 to receive the channels multiplexed by the channel  
11 combiner associated with said each input of the plurality  
12 of inputs of the second spatial switching fabric.

1 25. An optical router according to claim 24,  
2 wherein:

3 said each filter of the plurality of wavelength  
4 filters comprises a tunable band pass filter capable of  
5 separating different one or more wavelength channels; and

6 said each converter of the plurality of wavelength  
7 converters comprises a tunable pump source capable of  
8 producing pump output at different wavelengths to enable  
9 said each converter to convert the received add wavelength  
10 channel to different transformed wavelengths.

1 26. An optical router according to claim 24, further  
2 comprising:

3 a plurality of optical amplifiers, one amplifier of  
4 the plurality of amplifiers per channel combiner, each

5 amplifier of the plurality of amplifiers being interposed  
6 between the channel combiner associated with said each  
7 amplifier and the input of the plurality of inputs of the  
8 second spatial switching fabric associated with the  
9 channel combiner that is associated with said each  
10 amplifier.

1 27. An optical router according to claim 24, further  
2 comprising:

3 a plurality of optical switches, one switch of the  
4 plurality of switches per wavelength filter of the  
5 plurality of wavelength filters, each switch of the  
6 plurality of switches comprising an input, a first switch  
7 output, and a second switch output, said each switch being  
8 capable of receiving the bundle associated with the filter  
9 that is associated with said each switch and selectively  
10 transmitting the bundle associated with the filter that is  
11 associated with said each switch to the first or the  
12 second switch output of said each switch;

13 a redundant path channel combiner comprising an  
14 output and inputs coupled to the second switch outputs of  
15 the plurality of optical switches;

16 a redundant path wavelength filter capable of  
17 separating one or more wavelength channels from one of the  
18 bundles of wavelength channels;

19 a redundant path wavelength converter capable of  
20 receiving a redundant path add channel and converting the  
21 received redundant path add channel to a different  
22 wavelength;

23 a redundant path multiplexing unit coupled to the  
24 redundant path wavelength filter and to the redundant path  
25 wavelength converter, the redundant path multiplexing unit  
26 being capable of multiplexing at least a subset of  
27 channels of the one of the bundles of wavelength channels  
28 and the converted redundant path add channel;

29 wherein:

30 the plurality of channel combiners comprises a first  
31 channel combiner, the first channel combiner being coupled  
32 to the redundant path multiplexing unit; and

33 the first channel combiner is capable of multiplexing  
34 the channels received by the first channel combiner from  
35 the output of the first spatial switching fabric  
36 corresponding to the first channel combiner, the channels  
37 multiplexed by the multiplexing unit associated with the

38 first channel combiner, and the channels multiplexed by  
39 the redundant path multiplexing unit.

1 28. An optical router according to claim 27, wherein  
2 said each converter of the plurality of wavelength  
3 converters comprises a difference frequency mixer.

1 29. An optical router according to claim 28,  
2 wherein:

3 said each filter of the plurality of wavelength  
4 filters comprises a tunable band pass filter capable of  
5 separating different one or more wavelength channels; and  
6 the difference frequency mixer of said each converter  
7 of the plurality of wavelength converters comprises a  
8 tunable pump source capable of producing pump output at  
9 different wavelengths to enable said each converter to  
10 convert the received add wavelength channel to different  
11 transformed wavelengths.

1 30. An optical router according to claim 27, wherein  
2 said each converter of the plurality of wavelength  
3 converters comprises a cross-gain modulator.

1        31. An optical router according to claim 30,  
2 wherein:

3        said each filter of the plurality of wavelength  
4 filters comprises a tunable band pass filter capable of  
5 separating different one or more wavelength channels; and  
6        the cross-gain modulator of said each converter of  
7 the plurality of wavelength converters comprises a tunable  
8 pump source capable of producing pump output at different  
9 wavelengths to enable said each converter to convert the  
10 received add wavelength channel to different transformed  
11 wavelengths.

1        32. An optical router according to claim 27, wherein  
2 said each converter of the plurality of wavelength  
3 converters comprises a cross-phase modulator.

1        33. An optical router according to claim 32,  
2 wherein:

3        said each filter of the plurality of wavelength  
4 filters comprises a tunable band pass filter capable of  
5 separating different one or more wavelength channels; and  
6        the cross-phase modulator of said each converter of  
7 the plurality of wavelength converters comprises a tunable

8 pump source capable of producing pump output at different  
9 wavelengths to enable said each converter to convert the  
10 received add wavelength channel to different transformed  
11 wavelengths.

1 34. An optical router according to claim 27, wherein  
2 said each converter of the plurality of wavelength  
3 converters comprises a four-wave mixer.

1 35. An optical router according to claim 34,  
2 wherein:

3 said each filter of the plurality of wavelength  
4 filters comprises a tunable band pass filter capable of  
5 separating different one or more wavelength channels; and  
6 the four-wave mixer of said each converter of the  
7 plurality of wavelength converters comprises a tunable  
8 pump source capable of producing pump output at different  
9 wavelengths to enable said each converter to convert the  
10 received add wavelength channel to different transformed  
11 wavelengths.

1 36. An optical router according to claim 1, wherein  
2 said each filter of the plurality of wavelength filters  
3 comprises a tunable band pass filter characterized by a

4 passband with an adjustable bandwidth and an adjustable  
5 center wavelength, whereby said each filter of the  
6 plurality of wavelength filters is capable of separating a  
7 first wavelength channel of the one or more wavelength  
8 channels at different wavelengths and with variable  
9 channel separation.

1 37. An optical router according to claim 36, wherein  
2 said each converter of the plurality of wavelength  
3 converters comprises a tunable pump source capable of  
4 producing pump output at different wavelengths to enable  
5 said each converter to convert the received add wavelength  
6 channel to different transformed wavelengths.

1 38. An optical router for routing wavelength  
2 channels received in bundles of wavelength channels, the  
3 router comprising:

4 a plurality of wavelength filters, one filter of the  
5 plurality of wavelength filters per bundle, each filter of  
6 the plurality of wavelength filters being capable of  
7 separating one or more wavelength channels from the bundle  
8 associated with the filter;



9 a plurality of wavelength converters, one converter  
10 of the plurality of wavelength converters per bundle, each  
11 converter being capable of receiving an add wavelength  
12 channel and converting the received add wavelength channel  
13 to a transformed wavelength;

14 a first spatial switching fabric comprising a  
15 plurality of inputs and a plurality of outputs, the inputs  
16 of the first spatial switching fabric being coupled to the  
17 plurality of wavelength filters to receive the separated  
18 one or more wavelength channels;

19 a plurality of multiplexing units, one multiplexing  
20 unit of the plurality of multiplexing units per bundle,  
21 each multiplexing unit of the plurality of multiplexing  
22 units being coupled to a respective output of the  
23 plurality of outputs of the first spatial switching  
24 fabric, said each multiplexing unit of the plurality of  
25 multiplexing units being capable of multiplexing at least  
26 a subset of channels of the bundle associated with said  
27 each multiplexing unit, the add wavelength channel  
28 converted by the converter associated with the bundle that  
29 is associated with said each multiplexing unit, and  
30 channels received from the respective output of the

31 plurality of outputs of the first spatial switching  
32 fabric.

1 39. An optical router according to claim 38, wherein  
2 said each filter of the plurality of wavelength filters  
3 comprises a tunable band pass filter capable of being  
4 adjusted to separate different one or more wavelength  
5 channels.

1 40. An optical router according to claim 39, wherein  
2 said each converter of the plurality of wavelength  
3 converters comprises a tunable pump source capable of  
4 producing pump output at different wavelengths to enable  
5 said each converter to convert the received add wavelength  
6 channel to different transformed wavelengths.

1 41. An optical router according to claim 38, wherein  
2 said each multiplexing unit of the plurality of  
3 multiplexing units comprises a fused fiber optical power  
4 splitter.

1 42. An optical router according to claim 41, wherein  
2 the fused fiber optical power splitter of said each  
3 multiplexing unit of the plurality of multiplexing units

4 comprises active fiber filler capable of amplifying the  
5 wavelength channels multiplexed by said each multiplexing  
6 unit of the plurality of multiplexing units.

1 43. A router comprising:

2 a first wavelength selection module comprising an  
3 input port capable of receiving a first plurality of  
4 wavelength channels, a first wavelength filter capable of  
5 separating a first separated channel from the first  
6 plurality of wavelength channels, and a first pass-through  
7 output port for outputting wavelength channels of the  
8 first plurality of wavelength channels;

9 a second wavelength selection module comprising an  
10 input port capable of receiving a second plurality of  
11 wavelength channels, a second wavelength filter capable of  
12 separating a second separated channel from the first  
13 plurality of wavelength channels, and a second pass-  
14 through output port for outputting wavelength channels of  
15 the second plurality of wavelength channels;

16 a first wavelength conversion module comprising a  
17 first wavelength converter capable of receiving a first  
18 add channel at a first add wavelength and converting the  
19 first add channel to a first converted wavelength, a first

20 multiplexing unit coupled to the first pass-through port  
21 and to the first wavelength converter, the first  
22 multiplexing unit being capable of multiplexing the  
23 wavelength channels of the first plurality of wavelength  
24 channels received from the first pass-through port and the  
25 converted first add channel;

26 a second wavelength conversion module comprising a  
27 second wavelength converter capable of receiving a second  
28 add channel at a second add wavelength and converting the  
29 second add channel to a second converted wavelength, a  
30 second multiplexing unit coupled to the second pass-  
31 through port and to the second wavelength converter, the  
32 second multiplexing unit being capable of multiplexing the  
33 wavelength channels of the second plurality of wavelength  
34 channels received from the second pass-through port and  
35 the converted second add channel;

36 a first spatial switching fabric comprising a first  
37 input coupled to the first wavelength selection module to  
38 receive the first separated channel, a second input  
39 coupled to the second wavelength selection module to  
40 receive the second separated channel, and a plurality of  
41 outputs comprising a first output and a second output;

42 a first channel combiner coupled to the first output  
43 of the plurality of outputs of the first spatial switching  
44 fabric and to the first wavelength conversion module, the  
45 first channel combiner being capable of receiving and  
46 multiplexing wavelength channels from the first output of  
47 the first spatial switching fabric and the channels  
48 multiplexed by the first multiplexing unit; and

49 a second channel combiner coupled to the second  
50 output of the plurality of outputs of the first spatial  
51 switching fabric and to the second wavelength conversion  
52 module, the second channel combiner being capable of  
53 receiving and multiplexing wavelength channels from the  
54 second output of the first spatial switching fabric and  
55 the channels multiplexed by the second multiplexing unit.

1 44. A router according to claim 43, wherein:

2 the first wavelength filter comprises a first tunable  
3 band pass filtering element capable of being adjusted to  
4 separate the first separated channel in a range of  
5 wavelengths; and

6 the second wavelength filter comprises a second  
7 tunable band pass filtering element capable of being

8 adjusted to separate the second separated channel in a  
9 range of wavelengths.

1 45. A router according to claim 44, wherein the  
2 first wavelength converter comprises a tunable pump source  
3 capable of producing pump output at different wavelengths  
4 to enable said each converter to convert the first add  
5 channel to a first converted wavelength in a range of  
6 wavelengths.

1 46. An optical wavelength router comprising:  
2 first wavelength selection means for receiving a  
3 first plurality of wavelength channels from a first in  
4 fiber, and for selectively separating at least a first  
5 channel from the first plurality of wavelength channels;

6 second wavelength selection means for receiving a  
7 second plurality of wavelength channels from a second in  
8 fiber, and for selectively separating at least a second  
9 channel from the second plurality of wavelength channels;

10 first wavelength conversion means for receiving a  
11 first add wavelength channel at a first add wavelength and  
12 converting the first add wavelength channel to a first  
13 transformed wavelength;

14 second wavelength conversion means for receiving a  
15 second add wavelength channel at a second add wavelength  
16 and converting the second add wavelength channel to a  
17 second transformed wavelength;

18 first wavelength multiplexing means coupled to the  
19 first wavelength conversion means and to the first  
20 wavelength selection means, the first wavelength  
21 multiplexing means being for multiplexing at least a first  
22 subset of wavelength channels of the first plurality of  
23 wavelength channels and the converted first add wavelength  
24 channel;

25 second wavelength multiplexing means coupled to the  
26 second wavelength conversion means and to the second  
27 wavelength selection means, the second wavelength  
28 multiplexing means being for multiplexing at least a  
29 second subset of wavelength channels of the second  
30 plurality of wavelength channels and the converted second  
31 add wavelength channel;

32 first spatial switching means comprising a first  
33 input, a second input, a first output, and a second  
34 output, the first spatial switching means being for  
35 routing wavelength channels from the inputs of the first

36 spatial switching means to the outputs of the first  
37 spatial switching means;

38 first channel combiner means for combining wavelength  
39 channels appearing at the first output of the first  
40 spatial switching means and the wavelength channels  
41 multiplexed by the first wavelength multiplexing means;  
42 and

43 second channel combiner means for combining  
44 wavelength channels appearing at the second output of the  
45 second spatial switching means and the wavelength channels  
46 multiplexed by the second wavelength multiplexing means.

1 47. An optical wavelength router according to claim  
2 46, wherein:

3 the first wavelength selection means comprises first  
4 tunable band pass filter means capable of being adjusted  
5 to separate the first channel in a range of wavelengths;  
6 and

7 the second wavelength selection means comprises  
8 second tunable band pass filter means capable of being  
9 adjusted to separate the second channel in a range of  
10 wavelengths.



1        48. An optical wavelength router according to claim  
2 47, wherein the first wavelength conversion means  
3 comprises a first tunable wavelength conversion means for  
4 converting the first add wavelength channel to the first  
5 transformed wavelength in a range of wavelengths.

1        49. An optical wavelength router according to claim  
2 48, wherein the first tunable wavelength conversion means  
3 comprises a difference frequency mixer means for  
4 wavelength conversion.

1        50. An optical wavelength router according to claim  
2 48, wherein the first tunable wavelength conversion means  
3 comprises a cross-gain modulator means for wavelength  
4 conversion.

1        51. An optical wavelength router according to claim  
2 48, wherein the first tunable wavelength conversion means  
3 comprises a cross-phase modulator means for wavelength  
4 conversion.

1        52. An optical wavelength router according to claim  
2 48, wherein the first tunable wavelength conversion means

3 comprises a four-wave mixer means for wavelength  
4 conversion.

1 53. An optical wavelength router according to claim  
2 48, further comprising second spatial switching means  
3 comprising a first input, a second input, and a plurality  
4 of outputs, the first input of the second spatial  
5 switching means being coupled to the first channel  
6 combiner means to receive the wavelength channels combined  
7 by the first channel combiner means, the second input of  
8 the second spatial switching means being coupled to the  
9 second channel combiner means to receive the wavelength  
10 channels combined by the second channel combiner means,  
11 the second spatial switching means being for routing the  
12 wavelength channels combined by the first and the second  
13 channel combiner means from the first and second inputs of  
14 the second spatial switching means to the plurality of  
15 outputs of the second spatial switching means.

1 54. An optical wavelength router according to claim  
2 53, further comprising means for providing router path  
3 fault protection through redundancy.

1        55. An optical wavelength router according to claim  
2        54, further comprising:

3        first means for amplifying wavelength channels  
4        interposed between the first channel combiner means and  
5        the first input of the second spatial switching means; and  
6        second means for amplifying wavelength channels  
7        interposed between the second channel combiner means and  
8        the second input of the second spatial switching means.

1        56. An optical wavelength router according to claim  
2        46, wherein:

3        the first wavelength selection means comprises first  
4        tunable band pass filter means characterized by a first  
5        adjustable center wavelength and a first adjustable  
6        bandwidth; and

7        the second wavelength selection means comprises  
8        second tunable band pass filter means characterized by a  
9        second adjustable center wavelength and a second  
10        adjustable bandwidth.

1        57. An optical wavelength router according to claim  
2        56, wherein the first wavelength conversion means  
3        comprises a first tunable wavelength conversion means for

- 4 converting the first add wavelength channel to the first
- 5 transformed wavelength in a range of wavelengths.

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